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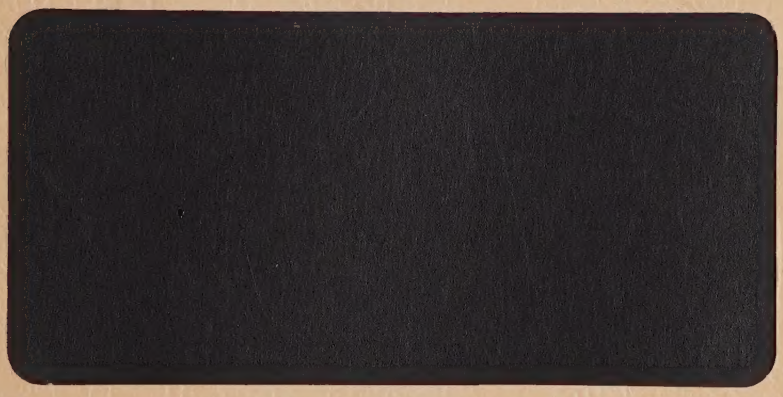

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE
CLEVELAND, OHIO

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INSTRUCTION MANUAL

MODEL 415

MICRO-MICROAMMETER

KEITHLEY INSTRUMENTS, INC.
CLEVELAND, OHIO

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WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof, except tubes, transistors, fuses, and batteries, which, within a year after shipment to the original buyer, proves defective on examination.

DAMAGE IN SHIPMENT

Be sure to include the instrument model number and serial number in all communications. If the instrument is damaged when received, or fails to operate properly, a claim should be filed with the carrier. Upon receipt of the claim agent's report, we will inform you regarding repair or replacement.

REPAIRS

When returning an instrument for repair or recalibration, it should be securely packed against shipping damage and sent to the factory, freight prepaid. A brief letter describing the difficulty should accompany the instrument.

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SECTION I - INTRODUCTION

The Model 415 Micro-microammeter incorporates advanced high-speed circuitry developed by Keithley Instruments for rocket and satellite experimentation -- where measurements of Lyman-Alpha night glow, cosmic radiation, and upper air density require fast response.

The 415 also provides zero suppression up to 100 full scales, permitting full scale display of one per cent variations of a signal, or suppression of a steady background signal.

Excelling other Keithley 400 Series Micro-microammeters in speed of response, the Model 415 is ideal for current measurements in ion chambers, ionization gages, and photo-multipliers.

Other applications include uses with flame and Beta-ray ionization detectors and in gas chromatography, mass spectrometry.

Speed of response of less than 600 milliseconds to 90% of final value at 10^{-12} ampere is possible where external circuit capacity is less than 50 picofarads (uuf). Critical damping of the circuit, with any input capacity, is maintained on all ranges through one infrequent adjustment. There is no possibility of oscillation or poor transient response on any range.

Accuracy is $\pm$ 2% of full scale on 10^{-3} through 10^{-8} ampere ranges; $\pm$ 3% of full scale on 3×10^{-9} through 10^{-12} ampere ranges.

Other features include capability of detecting current of approximately 1×10^{-14} ampere; zero stability of better than 2% per day and a one volt output at one milliampere; a 1% mirror scale panel meter.

SECTION II - SPECIFICATIONS

RANGES: 10^{-12}, 3 x 10^{-12}, 10^{-11}, 3 x 10^{-11}, etc. to 10^{-3} ampere full scale.

ACCURACY: ± 2% of full scale 10^{-3} thru 10^{-8} ampere ranges; ± 3% of full scale 3 x 10^{-9} thru 10^{-12} ampere ranges.

ZERO DRIFT: After 30-minute warmup, less than 2% of full scale per 24 hours on all ranges.

GRID CURRENT: Less than 5 x 10^{-14} ampere.

OUTPUT: One volt for full scale at up to 5 ma. Noise less than 20 millivolts.

RISE TIME: Typical value given in seconds to 90% of final value.

Range amps f.s.	Cin-50 uuf seconds	Cin-150 uuf seconds	Cin-1500 uuf seconds
10^{-12}	.600	.800	2.5
3 x 10^{-12}	.200	.300	1.0
10^{-11}	.060	.080	.250
3 x 10^{-11}	.020	.030	.100
10^{-10}	.006	.010	.030
3 x 10^{-10}	.002	.003	.010
10^{-9}	.001	.001	.003
3 x 10^{-9} and above	.001	.001	.001

CURRENT SUPPRESSION: Up to 100 full scales; maximum buckout 10^{-5} ampere. One setting of bucking current serves five adjacent ranges within above limits. FINE adjustment allows precise control up to 100 times suppression.

ZERO CHECK: Allows zeroing without disturbing the circuit.

TUBE COMPLEMENT: 2-5886, 2-6CB6, 1-6CM6, 1-12B4A; 2-12AX7, 1-0G3.

POWER: 100-130 v, 60 cps, 50 watts; 50 cps and 230 v units on special order.

ACCESSORIES SUPPLIED: Mating connectors for input, output; six foot power cord.

ACCESSORIES AVAILABLE: Model 6032 End Frames, mounting hardware, rubber feet. Model 4102 Input Assembly, 2-5886 electrometer tubes in a plug-in can (replacement spare).

CABINET: 19" x 5¼" high x 10" deep. Net weight 21 lbs.

SECTION III - OPERATION

A. OPERATING CONTROLS

The controls are discussed in order from left to right on the front panel.

(1) ZERO CHECK: Depressing this control effectively removes all current from the amplifier input and allows the meter to be set to zero with the ZERO ADJUST control. After the button is depressed it may be locked in position by turning the button one quarter turn as indicated by the panel marking.

(2) AMPERES FULL SCALE: The full scale meter sensitivity is selected by this control. The use of zero suppression does not change the sensitivity.

(3) CURRENT SUPPRESS:
   (a) MULTIPLIER and AMPERES: The combination of these two dials set the amount of zero suppression. On the OFF position of the AMPERES dial, the suppression circuit is disconnected.
   (b) FINE: The FINE control extrapolates between positions of the MULTIPLIER switch. For example when the MULTIPLIER control is on zero, the FINE control has a range of 0 to 1. If the control is on 1, the range of the FINE control is from 1 to 2 and so forth.

(4) METER: The METER switch allows the choice of plus or minus current polarity; using the meter for indication; or switching it off. In the METER OFF position, the switch still permits choice of plus or minus current polarity.

(5) ON: This switch turns on power. The instrument is ready to operate in about 60 seconds.

(6) ZERO ADJUST: This control is used with the ZERO CHECK button depressed to adjust the micro-microammeter zero.

B. INPUT AND OUTPUT CONNECTIONS

(1) Input Connections: The input connections and the current generator being measured must be carefully shielded since power line frequencies are well within the pass band of the amplifier on most ranges. Also, unless the electrostatic shielding is thorough, any alteration in electrostatic field in the neighborhood will cause marked output disturbances. The insulation

used in bringing the signal into the amplifier must be either polyethylene, polystryene, teflon or similar high resistance, low-loss material. Any Coaxial cables used must be of the low-noise type. This type of cable employs a graphite coating between the dielectric and the surrounding shield braid. Satisfactory types are made by Amphenol, Microdot and Simplex. The use of low-noise cable is mandatory due to the wide frequency response of the instrument. The Model 415 is, therefore, markedly more sensitive to external disturbances than other Keithley Electrometers. Any change in the capacitance of the measuring circuit to ground will cause extraneous disturbances. It is, therefore, recommended that the measuring set-up be made as rigid as possible and any connecting cables be tied down to prevent their movement. If continuous vibration is present, it may appear on the output as a sinusoidal signal and some precautions may be necessary to isolate the instrument and connecting cable from this vibration.

(2) Output Connections: The output of the instrument is one volt for full scale meter deflection. Up to 5 ma. may be drawn from the output. The output is intended primarily for driving oscilloscopes and pen recorders. It may be divided down to drive 10 and 50 millivolt recorders by placing a suitable network across the output. In general it will not satisfactorily drive 1 ma. Esterline-Angus and Texas Instruments recorders directly since the output voltage is too low for full scale deflection or for providing the proper coil damping.

C. PRELIMINARY SET-UP

(1) Connect current source to input terminals per directions in paragraph B1 above.

(2) Depress and lock ZERO CHECK button.

(3) Set CURRENT SUPPRESS controls as follows:

(a) MULTIPLIER: Set to zero.
(b) AMPERES: Set to OFF.
(c) FINE: Turn to most counter-clockwise position.
(d) METER: Turn to + position.

(4) Turn on power. After about 30 seconds meter should indicate on scale.

(5) Set meter to zero with ZERO ADJUST.

D. MAKING MEASUREMENTS

(1) Current Measurements Without Zero Suppression: With the current source attached and the AMPERES control on OFF, turn the AMPERES FULL SCALE switch to the most insensitive range and open the ZERO CHECK switch. Increase the instrument sensitivity until the largest possible reading is obtained before full scale is exceeded. The reading is now the actual current being generated by the attached device.

(2) Current Measurements With Zero Suppression: Proceed as in paragraph (1) above. Then set the CURRENT SUPPRESS MULTIPLIER and AMPERES dials to correspond as closely as their resolution permits to the current reading obtained in paragraph (1). This operation should cause the meter needle to approach zero. Now use the FINE control as necessary to set the meter exactly to zero. Then move AMPERES FULL SCALE switch to the next more sensitive range and adjust the FINE control as necessary. The input current is still the same. However, variations in current are being presented on a scale three times as sensitive as before. If it is desired to expand the scale further, the next more sensitive range may be used. This process may be repeated until one per cent of the original scale is presented as full scale. The zero suppression circuit is limited to this amount of suppression.

E. SPEED OF RESPONSE

The specifications detail the possible speed of reponse with various input capacities. It is evident from the data that the less the input capacity, the better the speed of response. Therefore, the Model 415 should be located as closely as possible to the current source. The amount of capacity does not affect the damping. Under all conditions, the response will be approximately critically damped.

$R = \frac{1}{I_{fs}}$, R in Ω , I_{fs} in amps

$A = 5000$

full scale out means 1V across R and 0.2 mV across input

$R_{in} = \frac{R}{A}$, $E_{in}(f.s.) = I_{fs} \times R_{in} = \frac{1}{A} = 0,2$ mV

SECTION IV - CIRCUIT DESCRIPTION

A. CIRCUIT BLOCK DIAGRAM

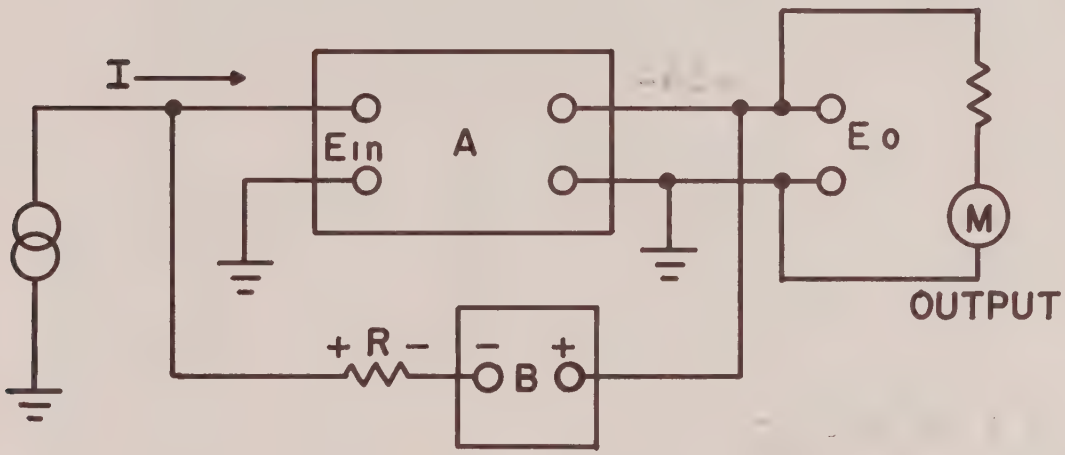


FIG. 1

(1) The Electrometer: In block A Figure 1 is a high gain amplifier with electrometer tube input. It can be assumed with a high degree of accuracy that current neither enters or leaves its input terminals. The amplifier is so arranged that the output is the negative of the input. Therefore, since a feedback connection exists between e_o and the input, any positive voltage appearing at the input of A, will cause a negative voltage applied through R and B. If, for the moment, we omit the box labeled B from the discussion, the voltage e_o will increase until it equals iR, the drop across the resistor. This is necessary since this feedback connection results in a circuit designed to keep the input drop to a minimum. Therefore, as a first approximation,

$$i = e_o/R \qquad (1)$$

and a properly calibrated meter at the amplifier output will read current directly.

(2) Current Suppression: In Figure 1, when an input current is flowing, the output voltage is iR from (1). The output assumes this voltage in order to balance out the input current so that the input terminal remains at ground. Either the output must supply this voltage, in which case the meter indicates a reading; or a voltage may be inserted in series with the feedback

resistor opposite in polarity and equal to the drop across the feedback resistor, R. In Figure 1, B represents this buckout voltage. If B is now adjusted to precisely the voltage across R, the meter will return to zero, since no voltage need be applied to keep the input at ground even though a current is flowing. This is the method used in the Model 415 for zero suppression. By having B variable from zero to 100 volts, up to 100 times zero suppression may be achieved if one full scale corresponds to a one volt drop across the feedback resistor, R.

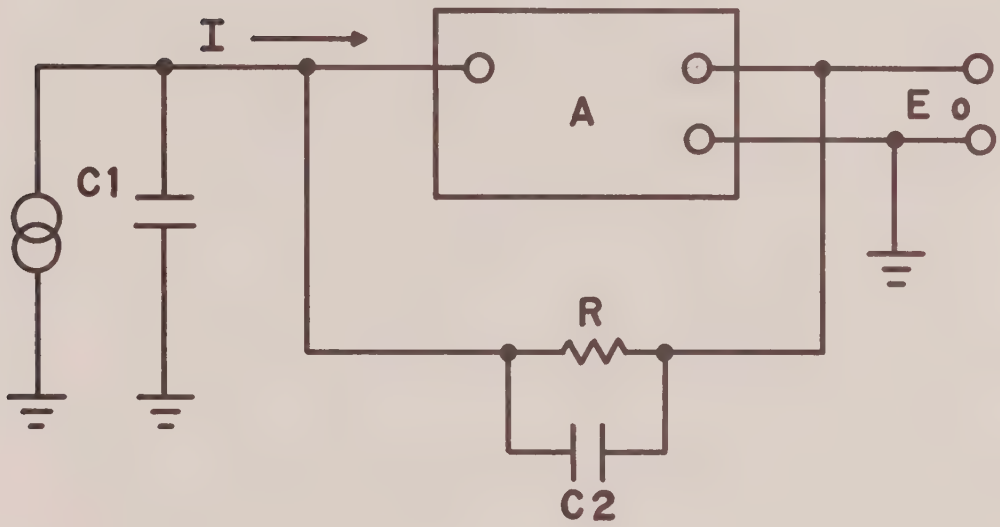


FIG. 2

B. SPEED OF RESPONSE:

In Figure 2, the circuit of Figure 1 is redrawn to show the capacities associated with the circuit. C_1 is the input capacity and C_2 is the capacity across the feedback resistor. The buck-out supply, has been omitted since it is by-passed for ac. The response of this circuit to a current step is given by

$$e_o = \frac{i R_1 k}{1 + k} \left[1 - \exp \left\{ \frac{-t}{R_1 \left(\frac{C_1}{1 + k} + C_2 \right)} \right\} \right] \qquad (2)$$

where the time constant T is

$$T = R_1 \left(\frac{C_1}{1 + k} + C_2 \right) \qquad (3)$$

It can be seen that the input capacity, C_1, is decreased in proportion to the loop gain, but that the effect of capacity across the high megohm resistor represented by C_2 is not affected. In the Model 415, the loop gain of the amplifier is approximately 5000, so that the time constant of the input capacitance is not too critical, except at very low currents. The time constant R_1C_2 with a 10^{12} ohm resistor, which is used on the most sensitive range, can amount to 10 seconds. Therefore, the effect of R_1C_2 must be eliminated if any speed of response is to be obtained.

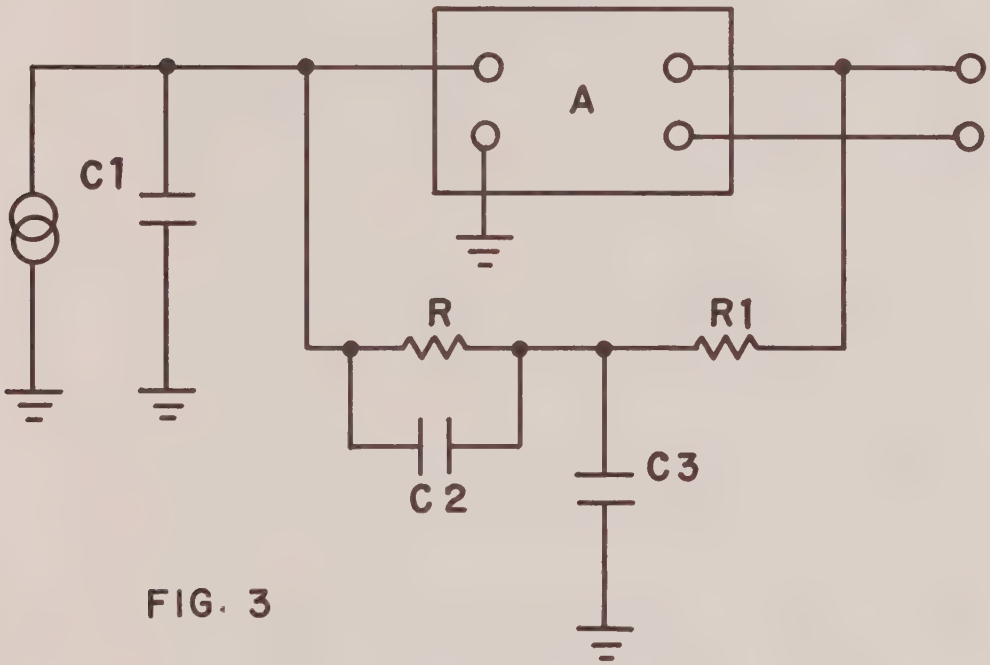


FIG. 3

To accomplish this, refer to Figure 3. R_1 and C_3 have been added to the feedback loop. If R_1C_3 now equals RC_2, we have a "lead" network cancelling a "lag" network and effectively equation (3) becomes:

$$T = \frac{R\,(C_1 + C_2)}{k + 1} \qquad (4)$$

where both capacities are degenerated by loop gain. With this arrangement the circuit is critically damped. The addition of more capacity to the input will affect the time constant as shown in (4). However, since basically the circuit is a one lag or single time constant feedback system, critical damping will not be affected by addition of capacity at the input. Moreover, the adjustment is

quite stable and is made at the factory. Slight misadjustment will not be serious and will not lead to oscillation.

C. DETAILED CIRCUIT DESCRIPTION

Refer to DR 13102D at rear of manual.

(1) Micro-microammeter: The micro-microammeter is contained in the Model 4102 input tube assembly, PC-10, and the associated windings of TR1. V-1 and V2 are electrometer tubes. V2 is a dummy tube which serves to cancel out changes in plate and filament voltages which otherwise would appear in the output. These tubes operate effectively as a long-tail pair due to feedback from the common cathode junction of V3 and V4 to the commonly connected screen electrodes of V1 and V2. V3 and V4 function as the second amplifier stage and V4 is connected as a cathode follower output stage. Feedback around the micro-microammeter is accomplished via the AMPERES FULL SCALE switch, SW1, selecting the various feedback resistors. One resistor is used per range and the feedback voltage is 1 volt on all ranges.

(2) Micro-microammeter Power Supply: The power supply for the instrument consists of a Sola regulating transformer and simple condenser-rectifier systems for obtaining the voltages for the various potentials used in the micro-microammeter.

(3) Zero Suppression Circuit: Zero suppresion is obtained by placing a dc voltage in series with the range resistor. In this way, the dc supply "bucks out" the input current flowing in the range resistor as explained in detail in paragraph A above.

The CURRENT SUPPRESS supply voltage is obtained from the power supply contained within the dotted lines labeled "PC 30" which corresponds to the printed circuit of the same designation in the instrument. The power supply furnishes extremely stable voltages, employing a 2-stage dc error-signal amplifier. Also, its input voltage and the filament voltages of the dc amplifier tubes are further regulated by the Sola regulating transformer. A detailed description of the operation of the regulator is contained in paragraph 4 below.

If the suppression circuit is to be used on several ranges, the suppression voltage must increase in the same ratio as range resistor, so that the same bucking current will be supplied.

The MULTIPLIER switch, SW-5, contains resistors R418 to R427. These resistors form a precision divider across the power supply. The arrangement is such that this switch selects the suppression voltage in ten volt steps from 0 to 100 volts. The full range of the FINE control corresponds to a change of ten volts. The METER switch, SW3, changes polarity of the suppression voltage so that it is

always in opposition to the input current polarity indicated on the panel meter.

Resistors R428 to R432 divide the selected voltage in the ratios 1, 3.3, 10, 33, and 100 for application to the range resistors.

The AMPERES switch, SW-6, applies the divided voltages in sequence to five resistors at a time depending on the suppression range desired. As an example, suppose it is desired to suppress 10^{-5} ampere. The MULTIPLIER switch, SW-5, would be set at "9" and the FINE control set fully clockwise so that 100 volts would be applied to R428 to R432. AMPERES switch, SW-6, would be set on the most clockwise position (in the schematic). Thus point K would be at 100 volts, point L at 33.3 volts, M at 10 volts, N at 3.3 volts and O at 1 volt.

Now on the AMPERES FULL SCALE switch, SW-1, when the 10^{-5} ampere range is used, the range resistor R115-100k is returned to point O, and point O is at one volt plus with respect to the T output. Thus the suppression circuit supplies $\frac{1 \text{ volt}}{100k} = 10^{-5}$ ampere, and the micro-microammeter reads zero. If the next range is selected, R114, a 333k resistor is used and returned to point N. Similarly, the 10^{-6}, 3 x 10^{-7} and 10^{-7} ranges are supplied with progressively increasing voltages, so that effectively 10^{-5} ampere is suppressed on each of these ranges. Therefore, any of these ranges may be used with the same suppression setting. With each change in suppression setting, the same sequence is set up for each current selected so that up to 100 times buck-out is available for any selected range. When using the zero suppression system, ranges on which the current indication would amount to less than one volt full scale are not connected into the suppression system, but the shunt resistors are returned directly to the output cathode. Range resistors on which more than 100 times full scale buck-out would be necessary are operated at 100 volts. This assures an off-scale reading, so that the user will be aware when he is asking for more buck-out than is possible with the system.] *

(4) Current Suppression Power-Supply: This power supply is a doubly-regulated, isolated source of 200 volts dc. This potential is divided down to provide buck-out as described in paragraph 3 above. The regulator consists of V-6, V-7, V8, and V9. The input to the regulator is supplied from T2 and rectifier-filter combination RF 105 and C406. T2 is supplied from a winding on T1, a Sola regulating transformer. This transformer also regulates the filaments of V6, V7 and V8 providing further stability. V6 is the series pass tube. Its output is compared against V9, the voltage reference tube, by V8 the comparator tube. The signal is further amplified by V7 and applied to the grid of V6 to control the output. This circuit supplies an exceedingly stable and transient-free voltage for the zero suppression circuit.

SECTION V - MAINTENANCE AND CALIBRATION

No periodic maintenance is necessary. Detailed trouble shooting instructions are given below. Calibration of the instrument, both in regard to dc accuracy and transient response, requires special equipment. The equipment will be described and the techniques given below. It is not advisable to alter any of the calibration adjustments unless it is in accord with the procedure as given below.

A. CALIBRATION

(1) D.C.: The initial calibration is performed on the 1 milliampere range with the CURRENT SUPPRESS off. R120, the 1k Calibrate Potentiometer, is set at precisely full scale with an accurate source of 1 milliampere. Now, if all the other resistors on AMPERES FULL SCALE switch SW-1 are correct in value, the instrument will be within the rated accuracy. It is necessary, however, to occasionally check the high megohm resistors (10^9 ohms and above) for accuracy. It is expected that the instrument will be within rated accuracy for two to three years from the time it leaves the factory. At the end of this time it will be likely that some of the higher value high-megohm resistors will have drifted out of tolerance and should be replaced.

In order to check these resistors, it is necessary to either check the value of these resistors in a bridge capable of better than 1% accuracy with resistances as high as 10^{12} ohms, or to be able to generate currents of this accuracy. If it is desired to generate currents of this accuracy, resistors in series with an accurate voltage source will have to have better than 1% known accuracy. Therefore, an accurate megohm bridge is necessary in either case. In check-out at the factory, the resistors are bridged, and the completed instrument is further checked with an accurate current source. In the field, unless an accurate megohm bridge such as the Keithley Model 515 Megohm Bridge is available, the instrument should be returned to the factory for calibration; or the high-meoghm resistors may be replaced at periodic intervals with a certified set from Keithley Instruments to assure absolute calibration accuracy.

(2) Transient Response Measurement: The rise time of the instrument is specified in response to a current step function. It must be emphasized at the outset that it is extremely difficult to generate such a current step with ordinary methods in the region of 10^{-9} to 10^{-12} ampere. A voltage supply, a high megohm resistor, and a switch are useless due to the inherent self-capacity of even the best resistor. More satisfactory methods are light modulation of a vacuum photo-tube output or generation of a current step by application of a ramp function to a capacitor.

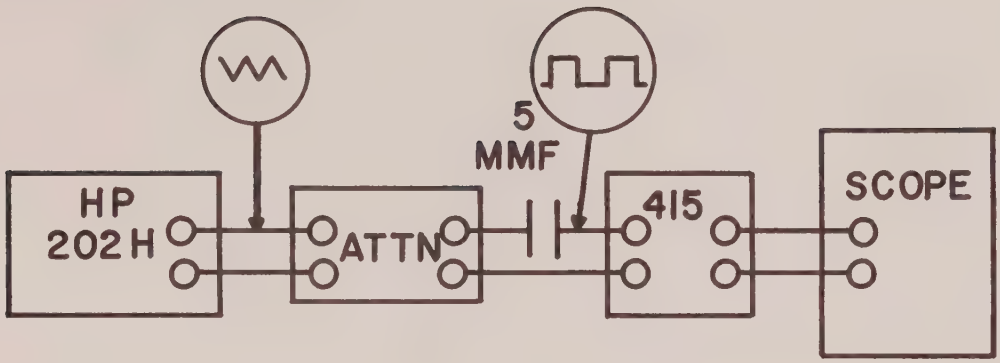


FIG 4

The second method is illustrated in Figure 4. A triangular wave generated by a Hewlett-Packard Model 202A Function Generator is fed through an attenuator into a 5 mmf polystyrene capacitor. The output is a current square wave whose amplitude is equal to

$$i = aC \qquad (1)$$

where i is the current amplitude, a is the slope of one segment of the triangular wave in volts per second, and C in farads is the capacitor coupling the signal into the 415. Under these circumstances, the current signal will be very nearly a perfect current step and an oscilloscope at the output will record the true transient response. If the signal displays sag or over-shoot, it is adjusted by means of R412 for the best square wave without overshoot.

(3) Calibration of Buck-Out Supply: Turn MULTIPLIER switch, SW5, to 9, AMPERES switch, SW6, to 10^{-5}, and FINE control fully clockwise. Now with 10^{-5} ampere exactly flowing into the input terminal, set the instrument on the 10^{-7} ampere range. Then adjust R414 so that the panel meter reads as close to zero as possible. Since the absolute precision of the buck-out is not high, an approximate setting will suffice.

B. TROUBLE SHOOTING

(1) General Procedure: If instrument will not balance with ZERO CHECK suppressed, determine if the trouble is in the CURRENT suppress supply or the micro-microammeter by turning the AMPERES switch, SW6, to OFF. If the zero can now be set by depressing the ZERO CHECK button, and if the instrument measures current on various ranges correctly, the fault is

in the buck-out supply. Otherwise it is in the micro-microammeter.

(2) Next, check to be sure that the supply voltages as indicated on the schematic are correct. The plus and minus potentials used in the micro-microammeter are all approximately 130 volts. The ac ripple should be less than 1 volt RMS on all supplies. If a defect is noted here, it is caused either by a defective rectifier or capacitor, or possibly by a defective resistor in the filter circuits. It is possible, in some cases, that an excessive load is being placed on the supply due to a micro-microammeter component failure. Removal of the output tube will remove most of the load. If the voltage then returns to normal, the defect is probably in the micro-microammeter.

(3) Each section will now be considered separately.

(a) Instrument will not balance with ZERO CHECK depressed: In a dc amplifier, any defect occurring between the input and output terminals usually will lead to an inability to balance the amplifier. In trouble-shooting, the usual impulse is to replace tubes first and ask questions later. It is advisable in this case to avoid this procedure unless it is shown that the tubes are actually defective, since the stability of the unit revolves mainly around the input tubes. If these tubes are three years old, but functioning properly, they most likely will be far superior in stability to any new tubes. Furthermore, electrometer tubes are seldom the cause of the difficulty. Therefore, follow the procedure outlined below.

Directly short the input terminal to ground. This removes the feedback. When this is done the effective forward loop gain rises and it becomes difficult to hold some of the operating potentials of the later stages at their proper value. This, however, is a normal effect and it is only necessary that it be possible to swing the electrode potential through the correct operating voltage by manipulating the ZERO control to show that the point in question is at correct potential.

With the input shorted measure the potential at pin 1 of V3 and turn the ZERO control through its range. The potential should swing through 10 volts near the middle of the ZERO control range. If it does not, check pin 3 on the input tube assembly connector. The voltage should be about 3.8 volts. If it is 130 volts, V-1 has an open filament and should be replaced.

If the filament voltage is correct, check to see if the screen voltage is correct. If it is not approximately correct, the defect may be either in the following stage, since the screens are connected to the

cathodes of V3 and V4, or it may be in V1 or V2. If the screen voltage is markedly different from 8 volts, check pin 7 of the input tube assembly connector. Again, if 130 volts is measured instead of 3.8 volts, the filament of V2 is open. If the filament checks correctly, measure the voltage on pin 1 of V4 while rotating the ZERO control. If this plate voltage is off and cannot be brought to 10 volts, as well as the plate of V1, the fault probably is in the second stage. Check at this point, if changing V3 and V4 will bring the instrument back into operation. With the input shorted to ground and instrument operating, the output will be unstable but should be able to swing rapidly through zero.

If this does not solve the trouble, change the electometer tubes V1 and V2. If this is not the cause of the defect, check the values of the various circuit components associated with the two stages.

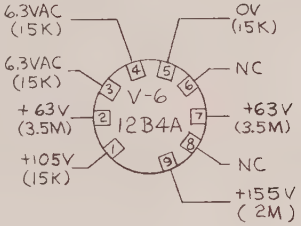
If on the other hand, the correct voltages are found on pins 1 of V3 and V4, check the voltage on pin five of V4. It should swing through plus 50 volts on manipulation of the ZERO control. If it does not, V3 or V4 is defective or a component associated with that stage is defective. Finally, if the correct voltage is obtained on the plate of V4, check to see that pin 3 of V5 will swing through about minus 14 volts.

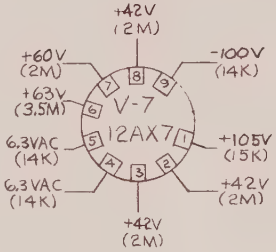
If it does not either R136, R137 or C122 is defective. If it does have the correct value, V5 is defective or R138 is defective.

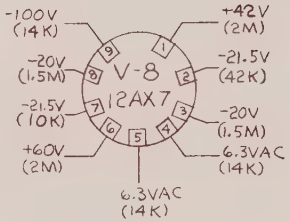
Now, when the short at the input is removed the instrument should function properly.

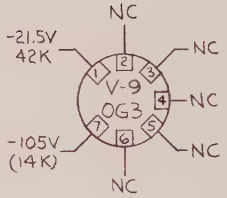
(b) Trouble Shooting the Power Supply: The most likely malfunction in the power supply is a tube failure, and it is recommended that tube replacement be tried first. If this does not eliminate the trouble, check to see that between B + floating and pin 9 of V-6 there is approximately 300 volts. If not, remove V6 and check the potential again. If it is now normal, the trouble is on the cathode side of the tube. If the potential is still low, check the output of the transformer, the rectifiers RF104 to 106, C406 and R406.

If it is determined that the trouble is on the cathode side of V6, check C411 and C408. If these procedures do not solve the difficulty it will be necessary to check the resistors R414 to R427 for correct value and to check the value of the other power supply components.

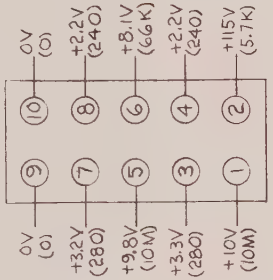


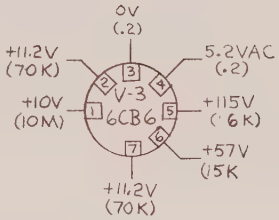


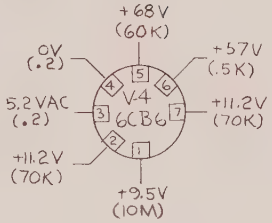


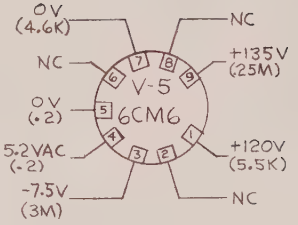


PC 37









PC10

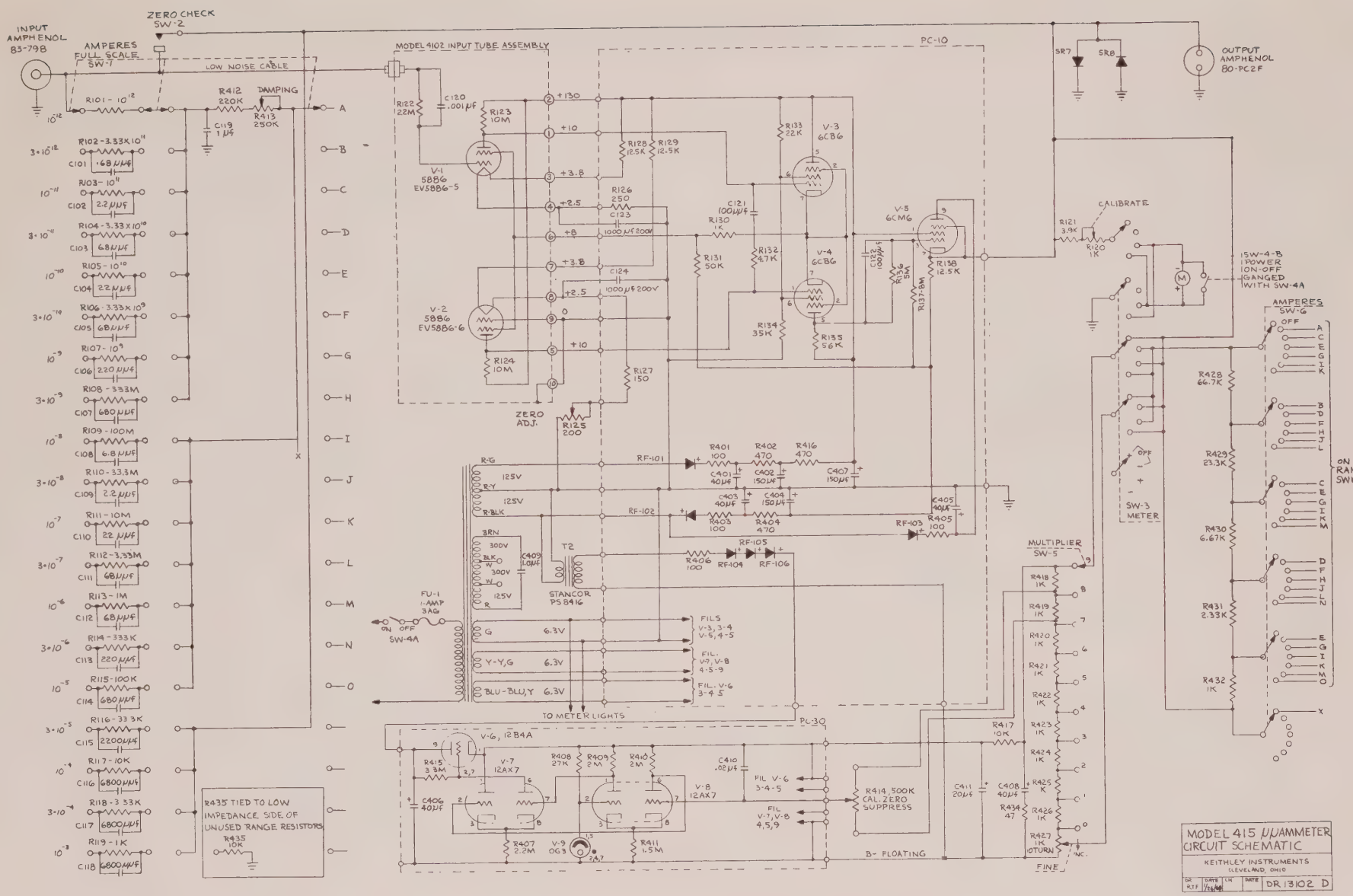
MODEL 415
VOLTAGE AND RESISTANCE CHART

MEASUREMENTS FROM TUBE PIN TO GROUND USING VTVM WITH 11 MEGOHM INPUT RESISTANCE.

CONTROLS SET AS FOLLOWS: METER SWITCH +ON
BUCKOUT OFF — RANGE 10^{-3}
OUTPUT CAPPED — METER SWITCH ZEROED

ALL READINGS ARE APPROXIMATE
RESISTANCES ARE GIVEN IN OHMS; K=1000; M=MEGOHMS.

TITLE: MODEL 415 VOLTAGE & RESISTANCE CHART		KEITHLEY INSTRUMENTS, INC. CLEVELAND, OHIO
DRAWN RTF	DATE 5/10/60	DRAWING NUMBER
CHECKED	DATE	13420 C
APPROVED	DATE	


INPUT AMPHENOL 83-79B
ZERO CHECK SW-2
AMPERES FULL SCALE SW-1
LOW NOISE CABLE
R101 - 10^12
R412 220K
DAMPING R413 250K
C119 1 μf
MODEL 4102 INPUT TUBE ASSEMBLY
PC-10
R122 22M
C120 .001 μf
R123 10M
R124 10M
R125 200
ZERO ADJ.
R126 250
C123 1000 μf 200V
C124 1000 μf 200V
R127 150
R128 12.5K
R129 12.5K
R130 1K
C121 100 μf
R131 50K
R132 4.7K
R133 22K
R134 35K
R135 56K
R136 12.5K
R137 8M
C122 100 μf
V-1 5886 EV5886-5
V-2 5886 EV5886-6
V-3 6CB6
V-4 6CB6
V-5 6CM6
+130
+10
+3.8
+2.5
+8
+3.8
+2.5
0
+10
SR7
SR8
OUTPUT AMPHENOL 80-PC2F
CALIBRATE
R121 3.9K
R120 1K
SW-4-B POWER ON-OFF GANGED WITH SW-4A
AMPERES SW-6
OFF
SW-3 METER
R428 66.7K
R429 23.3K
R430 6.67K
R431 2.33K
R432 1K
ON RANGE SWITCH
R101 - 10^12
R102 - 3.33X10^11 C101 .68 μf
R103 - 10^11 C102 2.2 μf
R104 - 3.33X10^10 C103 68 μf
R105 - 10^10 C104 22 μf
R106 - 3.33X10^9 C105 68 μf
R107 - 10^9 C106 220 μf
R108 - 333M C107 680 μf
R109 - 100M C108 6.8 μf
R110 - 33.3M C109 2.2 μf
R111 - 10M C110 22 μf
R112 - 3.33M C111 68 μf
R113 - 1M C112 68 μf
R114 - 333K C113 220 μf
R115 - 100K C114 680 μf
R116 - 33.3K C115 2200 μf
R117 - 10K C116 6800 μf
R118 - 3.33K C117 6800 μf
R119 - 1K C118 6800 μf
R435 TIED TO LOW IMPEDANCE SIDE OF UNUSED RANGE RESISTORS
R435 10K
RF-101
RF-102
RF-103
RF-104
RF-105
RF-106
R401 100
R402 470
R403 100
R404 470
R405 100
R406 100
R416 470
C401 40μf
C402 150μf
C403 40μf
C404 150μf
C405 40μf
C407 150μf
R-G 125V
R-Y 125V
R-BLK
3RN 300V BLK-W 300V W-R 125V
C409 1.0μf
T2
STANCOR PS8416
FU-1 1-AMP 3AG
ON OFF SW-9A
G 6.3V
Y-Y,G 6.3V
BLU-BLU,Y 6.3V
FILS V-3, 3-4 V-5, 4-5
FIL. V-7, V-8 4-5-9
FIL. V-6 3-4-5
TO METER LIGHTS
PC-30
V-6, 12B4A
V-7 12AX7
V-8 12AX7
V-9 OG3
R415 3.3M
R407 2.2M
R408 27K
R409 2M
R410 2M
R411 1.5M
C406 40μf
C410 .02μf
FIL V-6 3-4-5
FIL V-7, V-8 4,5,9
R414 500K CAL. ZERO SUPPRESS
B- FLOATING
MULTIPLIER SW-5
R417 10K
R418 1K
R419 1K
R420 1K
R421 1K
R422 1K
R423 1K
R424 1K
R425 1K
R426 1K
R427 1K
R434 47
C411 20μf
C408 40μf
TURN
FINE
INC.
MODEL 415 μμAMMETER CIRCUIT SCHEMATIC
KEITHLEY INSTRUMENTS CLEVELAND, OHIO
DR 13102 D

REPLACEABLE PARTS LIST - MODEL 415

Circuit Designation	Description			Part No.
C-102	Capacitor, 500 V. ± 5% Tolerance	2.2	mmf.	C56-2.2
C-103	Capacitor, 500 V. ± 5% Tolerance	6.8	mmf.	C56-6.8
C-104	Capacitor, 200 V. ± 5% Tolerance	22.	mmf.	C55-22
C-105	Capacitor, 200 V. ± 5% Tolerance	68.	mmf.	C55-68
C-106	Capacitor, 200 V. ± 5% Tolerance	220.	mmf.	C55-220
C-107	Capacitor, 200 V. ± 5% Tolerance	6800.	mmf.	C55-680
C-108	Capacitor, Same as C-103			
C-109	Capacitor, Same as C-102			
C-110	Capacitor, Same as C-104			
C-111	Capacitor, Same as C-105			
C-112	Capacitor, Same as C-105			
C-113	Capacitor, Same as C-106			
C-114	Capacitor, Same as C-107			
C-115	Capacitor, 200 V. ± 5% Tolerance	2200.	mmf.	C55-2200
C-116	Capacitor, 200 V. ± 5% Tolerance	6800.	mmf.	C55-6800
C-117	Capacitor, Same as C-116			
C-118	Capacitor, Same as C-116			
C-119	Capacitor, 200 V.	1.0	mfd.	C18-1
C-120	Capacitor, 600 V. 20% Tolerance	.001	mfd.	C22-.001
C-121	Capacitor, 600 V. 20% Tolerance	100.	mmf.	C22-100
C-122	Capacitor, Same as C-121			
C-123	Capacitor, 12 V.	1000.	mfd.	C11-1000
C-124	Capacitor, Same as C-123			

REPLACEABLE PARTS LIST - MODEL 415

Circuit Designation	Description			Part No.
C-401	Capacitor, Electrolytic	40 x 250 V.		C27-40
C-402	Capacitor, Electrolytic	150 x 150 V.		C9-150
C-403	Capacitor, Same as C-401			
C-404	Capacitor, Same as C-402			
C-405	Capacitor, Same as C-401			
C-406	Capacitor, Electrolytic	40 x 450 V.	ONE CAN	C33-40/40/20
C-407	Capacitor, Same as C-402			
C-408	Capacitor, Same as C-406			
C-409	Supplied with T-1, 1.0 mfd.			
C-410	Capacitor, Ceramic Disc	.02 x 600 V.		C22-.02
C-411	Capacitor, Electrolytic	20 x 450 V.		C33-40/40/20
FU-1	Fuse,	1.5 amp. 3 AG		FU-8
M-1	Meter			ME-23
R-101	Resistor, HiMeg Spiral	2%, 10^{12}		R20A-10^{12}
R-102	Resistor, HiMeg Spiral	2%, 3.33 x 10^{11}		R20A-3.33x10^{11}
R-103	Resistor, HiMeg Spiral	2%, 10^{11}		R20A-10^{11}
R-104	Resistor, HiMeg Spiral	2%, 3.33 x 10^{10}		R20A-3.33x10^{10}
R-105	Resistor, HiMeg Spiral	2%, 10^{10}		R20A-10^{10}
R-106	Resistor, HiMeg Spiral	2%, 3.33 x 10^{9}		R20A-3.33x10^{9}
R-107	Resistor, HiMeg Spiral	2%, 10^{9}		R20A-10^{9}
R-108	Resistor, HiMeg Spiral	2%, 3.33 x 10^{8}		R20A-3.33x10^{8}
R-109	Resistor, Deposited Carbon	1%, 2 watt,	100 M	R14-100M
R-110	Resistor, Deposited Carbon	1%, 1 watt,	33.3 M	R13-33.3M
R-111	Resistor, Deposited Carbon	1%, 1 watt,	10 M	R13-10M
R-112	Resistor, Deposited Carbon	1%, ½ watt,	3.33 M	R12-3.33M

REPLACEABLE PARTS LIST - MODEL 415

Circuit Designation	Description		Part No.
R-113	Resistor, Deposited Carbon 1%, ½ watt	1 M	R12-1M
R-114	Resistor, Deposited Carbon 1%, ½ watt	333 K	R12-333K
R-115	Resistor, Deposited Carbon 1%, ½ watt	100 K	R12-100K
R-116	Resistor, Deposited Carbon 1%, ½ watt	33.3 K	R12-33.3K
R-117	Resistor, Deposited Carbon 1%, ½ watt	10 K	R12-10K
R-118	Resistor, Deposited Carbon 1%, ½ watt	3.33K	R12-3.33K
R-119	Resistor, Deposited Carbon 1%, ½ watt	1 K	R12-1K
R-120	Potentiometer, Carbon - Linear Taper	1 K	RP3-1K
R-121	Resistor, Deposited Carbon 1%, ½ watt	3.9 K	R12-3.9K
R-122	Resistor, Composition 10%, ½ watt	22 M	R1-22M
R-123	Resistor, Deposited Carbon 1%, 1 watt	10 M	R13-10M
R-124	Resistor, Deposited Carbon Same as R-123		
R-125	Potentiometer, 200 ohm		RP23-200
R-126	Resistor, Wire Wound 1%, 25 watt	250 ohm	R18-6-250
R-127	Resistor, Wire Wound 1%, 25 watt	150 ohm	R18-6-150
R-128	Resistor, Wire Wound 3%, 7 watt	12.5 K	R7-12.5K
R-129	Resistor, Wire Wound Same as R-128		
R-130	Resistor, Deposited Carbon Same as R-119		
R-131	Resistor, Deposited Carbon 1%, ½ watt	50 K	R12-50K
R-132	Resistor, Deposited Carbon 1%, ½ watt	4.7 K	R12-4.7K
R-133	Resistor, Deposited Carbon 1%, ½ watt	22 K	R12-22K
R-134	Resistor, Deposited Carbon 1%, ½ watt	35 K	R12-35K
R-135	Resistor, Deposited Carbon 1%, ½ watt	56 K	R12-56K
R-136	Resistor, Deposited Carbon 1%, ½ watt	5 M	R12-5M
R-137	Resistor, Deposited Carbon 1%, 1 watt	8 M	R13-8M
R-138	Resistor, Wire Wound Same as R-128		

REPLACEABLE PARTS LIST - MODEL 415

Circuit Designation	Description			Part No.
R-401	Resistor, Composition	½ watt, 10%	100 ohm	R1-100
R-402	Resistor, Composition	½ watt, 10%	470	R1-470
R-403	Resistor, Same as R-401			
R-404	Resistor, Same as R-402			
R-405	Resistor, Same as R-401			
R-406	Resistor, Same as R-401			
R-407	Resistor, Composition	½ watt, 10%	2.2 M	R1-2.2M
R-408	Resistor, Composition	2 watt, 10%	27 K	R3-27K
R-409	Resistor, Deposited Carbon	½ watt, 1%	2 M	R12-2M
R-410	Resistor, Same as R-409			
R-411	Resistor, Deposited Carbon	½ watt, 1%	1.5 M	R12-1.5M
R-412	Resistor, Composition	½ watt, 10%	220 K	R1-220K
R-413	Potentiometer, Carbon - Linear Taper		250 K	RP2-1-250K
R-414	Potentiometer, Carbon - Linear Taper		500 K ohm	RP7-3-500K
R-415	Resistor, Composition	½ watt, 10%	3.3 M	R1-3.3M
R-416	Resistor, Same as R-402			
R-417	Resistor, Same as R-117			
R-418	Resistor, Same as R-119			
R-419	Resistor, Same as R-119			
R-420	Resistor, Same as R-119			
R-421	Resistor, Same as R-119			
R-422	Resistor, Same as R-119			
R-423	Resistor, Same as R-119			
R-424	Resistor, Same as R-119			
R-425	Resistor, Same as R-119			
R-426	Resistor, Same as R-119			

REPLACEABLE PARTS LIST - MODEL 415

Circuit Designation	Description	Part No.
R-427	Helipot, Type A 5% Tolerance, .5% Linearity 1 K. ohm, 10 T.	RP4-1K
R-428	Resistor, Deposited Carbon ½ watt, 1% 66.7 K	R12-66.7K
R-429	Resistor, Deposited Carbon ½ watt, 1% 23.3 K	R12-23.3K
R-430	Resistor, Deposited Carbon ½ watt, 1% 6.67 K	R12-6.67K
R-431	Resistor, Deposited Carbon ½ watt, 1% 2.33 K	R12-2.33K
R-432	Resistor, Same as R-119	
R-433		
R-434	Resistor, Composition ½ watt, 10% 47 ohm	R1-47
R-435	Resistor, Same as R-117	
RF-101	Rectifier, Selenium, 65 ma/130 V	RF-18
RF-102	Rectifier, Same as RF-101	
RF-103	Rectifier, Same as RF-101	
RF-104	Rectifier, Same as RF-101	
RF-105	Rectifier, Same as RF-101	
RF-106	Rectifier, Same as RF-101	
T-1	Transformer, Sola - 71354	TR-17
T-2	Transformer, Primary - 117 VAC/60 cycle	TR-20
SR-7	Rectifier, Selenium Diode 65 ma/240 V	RF-21
SR-8	Rectifier, Same as SR-7	
SW-1	Range Switch DR 13204-A	SW-72
SW-2	Zero Check DR 13400-A	SW-74-A
SW-3	Meter Switch DR 13203-A	SW-82
SW-4A	On - Off } Combined DPDT	SW-14
SW-4B	Meter Shorting }	

REPLACEABLE PARTS LIST - MODEL 415

Circuit Designation	Description		Part No.
SW-5	Buckout Multiplier Switch	DR 13212-A	SW-83
SW-6	Input Shielding Switch	DR 13330-A	SW-89
V-1	Tube, Vacuum 5886		EV 5886-5
V-2	Tube, Vacuum 5886		EV 5886-6
V-3	Tube, Vacuum 6CB6		6 CB 6
V-4	Tube, Same as V-3		
V-5	Tube, Vacuum 6CM6		6 CM 6
V-6	Tube, Vacuum 12B4A		12 B4 A
V-7	Tube, Vacuum 12 AX7		12 AX 7
V-8	Tube, Same as V-7		
V-9	Tube, Gas OG3		EV-OG 3

545
Amfile
WHITE